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Notes on the possible effect of reservoirs on local climate.

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Introduction: These notes were prepared for an enquiry and they are put together for easy reference. They do not claim to be comprehensive but may serve as an introduction to the literature on the topic. All the publications are held in the Meteorological Office Library.

Any comments or suggestions on this paper should be sent to the author.

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NOTES ON THE POSSIBLE EFFECT OF RESERVOIRS ON LOCAL CLIMATE

1. Lewinska J, 1965. A conception of meteorological investigations on the influence of water reservoirs on local climate. Warsaw, Panst. Inst. Hydr. Met., Wiad-Sluzby Hydr. Met. 2, Zes 1, pp.3-12

Quotes Milata on the effects of water reservoirs in the Danube basin and it is inferred that "climatic changes are limited to small areas of the valley and to those parts of the year in which the reservoirs are in action". These inferences "cannot be final when the whole question requires extension into the field of long-period soundly based investigation".

Dealing with the dam "Kościusko" at Wiśla-sub-Krakow, Wiszniewski and Zych came to the conclusion that the construction of the dam did not cause any change even on the mesoclimatic scale. There are similar conclusions concerning the dam "Ciechocinek"; the authors (Paszyński, Szczęsna and Zych) assert that "the range of effects caused by the building of the dam will not be too large" and "will be limited to a local nature".

Russian work is quoted - the effects of reservoirs is related to their size and to the formation of the terrain and the range of the effect is different with respect to individual climate parameters. Sapožnikowa says that the effect of the reservoir decreases to a first approximation, with the logarithm of the distance.

For Polish conditions we have not succeeded up to now in establishing any quantitative or qualitative changes in climate brought about by the effect of artificial lake reservoirs.

The remainder of the paper deals with need for special investigations to determine the climatic effects of constructing reservoirs. Dealing with the question of precipitation it is stated that "the present view is that the effect of water reservoirs on the regime of atmospheric precipitation is limited to increasing the frequency of slight precipitation and hence the number of days with precipitation and that they have no significant effect on the production of precipitation".

2. Lewińska J, 1967. Method of forecasting the influence of water reservoirs on the local climate. Warsaw, Panst. Inst. Hydr. Met., Wiad-Sluzby Hydr. Met.3, Zes 1, pp.9-17

This describes a method of "forecasting" the effect of reservoirs, but the observations were apparently made after the reservoir was constructed and were compared with observations made in another area without a reservoir, but "with the same physiographic conditions". It is assumed that any difference between data for the sites is due to the water.

Various difference indicators were worked:

$$K = \frac{Xy1 - Xy2}{Xy1}$$

where K = difference indicator

$Xy1$ = value of meteorological element at the reference station

Xy_2 = value of meteorological element affected by reservoir

These difference indicators may be applied to the physiographically similar area, using

$$X_{forecast} = X_a + X_aK$$

where X_a is an actual value.

One needs:

1) data from reservoir vicinity

2) data from point well away from reservoir, and not affected by it

3) area to which results are to be applied

An indication is given of the transposition of results from the Roznow reservoir to the proposed Pieniny reservoir.

A map is given of the forecast of local climatic variations near a reservoir, more qualitative than quantitative.

Yearly mean temperature is expected to increase, largely as a result of higher night temperatures: the midday temperatures are expected to be lower.

3. Petterssen S and Calabrese P A, 1959. On some weather influences due to warming of the air by the Great Lakes in winter. AFCRC-TN-59-260. Chicago Univ. Dept. Met. Contract No AF.19 (604) 2179, Sc. Rep. No.7: pp.20

The effect of the Great Lakes on the motion and precipitation patterns during a cold spell (Feb 8-14, 1958) is investigated. In general, the precipitation patterns caused by snow flurries from the Lakes revealed marked orographic influences. Well defined patterns, with a band of maximum precipitation about 15-25 miles from the shore, were found to occur persistently over the flat plains of northern Indiana and south-western Michigan. Evidence is produced to show that these patterns are related to the non-adiabatic cooling and decrease in lapse rate of the air that moves from the open water of Lake Michigan over the colder land. The largest amounts of precipitation from lake flurries alone are not likely to exceed about 0.2 in/day over flat land, though much larger amounts will be observed where orographic influences are strong.

4. Marzec Z and Okolowicz W, 1966. The influence of the Rożnów reservoir on some of the meteorological elements in the Dunajec valley. Belgrade, Prirod-mat-Facult., Met. Zav., Savez. Hidromet, Zav., Einfluss der Karpaten Witterung-serscheinungen: pp.373-7

Rożnów reservoir is an artificial lake created in 1941. In natural lakes the warm surface waters are drawn away by natural (surface) flow, but not in Lake Rożnów. In dammed lakes, the lower levels of water are drawn off by turbines so that surface temperatures remain high. The Rożnów reservoir is over 20 km long, has a maximum width of about 1.5 km and a depth of over 30 m. A number of stations situated within the Dunajec valley have been used for climatic comparison, Rożnów and Tegoborze are influenced by the reservoir but Nowy Sacz, Świniarsko and Brzeźna are not - they are about 10 km from the reservoir.

Mean monthly air temperatures are given for the 5 year period (July to September).

July-August, differences amount to 0.6°C or less, September 0.9°C, October 0.7°C, November 0.5°C, December 0.6°C.

In all of these months, the areas near the reservoir are warmer.

The largest differences are noticeable in typical radiation weather. Thermograph given for 2-7 October 1961 which shows clearly how the amplitude of temperature is reduced near the reservoir. /This certainly supports ideas of reduced frost frequency near reservoirs./ A graph of daily values of minimum temperature in October 1960 shows that the temperatures near the reservoir may be up to about 9°C higher than at more distant stations. During the day, when the reservoir is generally cooler, differences are not so great.

Relative humidity. Monthly averages may be 1-2% higher near the reservoir (July-December) and there seems to be very little difference (if any) in precipitation (values not given).

5. D'yakonov K N and Reteyum A Yu, 1964. The local climate of the Rybinsk Reservoir. Moscow, Akad. Nauk. Izv., Ser. Geog., No.4: 47-54

Abstract. The Rybinsk reservoir has had the effect of increasing wind velocity, especially at night, raising night-time and lowering daytime temperatures in the first half of summer and producing a round-the-clock warming effect in late summer and autumn. The warming effect in turn tends to lower relative humidity at night while increases are observed in the daytime. Note that paper is confined to months April to November.

Study is based on data for 1952 to 1961 from 6 shore stations, one in the centre of the reservoir and 2 representative continental stations outside the sphere of influence of the reservoir.

The reservoir covers area of 4,570 km^2 (approx. 1800 sq.m.) of which 40% is shallow water.

Spring heating of reservoir is rapid and extends throughout entire depth but in summer, high turbidity leads to stratification and maximum (surface) temperatures exceed 20°C (usually in June). Heated masses of water may be driven by light constant winds with little change of temperature. Differences in water temperatures between leeward and windward shores may be as high as 5-6°C.

Winds are also affected when forests, meadows and bogs are replaced by a body of water. A local circulation may be set up, particularly in quiet summer weather. The effects are most noticeable at night when the lake/land temperature gradient is most marked. Light winds are less frequent as a result of the reservoir and strong winds are more frequent. This increase in strong winds (in July) is much more marked at night than during the day. With light winds, the directions are changed to conform with the distribution of land and sea but with strong winds there is a much more marked tendency to blow off the water.

Over the reservoir there is a velocity maximum at night with a minimum by day and the reverse is true on land. Along the shore, there is a double maximum, by day and by night. These differences are due to changes in thermal stability over the different surfaces during the 24 hours.

A comparison of lake, lakeside and more continental temperatures shows that the effect of the lake on mean temperature near the lake is that of a gradual warming from April to October, the same general effect is true for maximum temperatures but

for minimum temperature the warming is greatest in J-J-A and then falls off. The effect on the minimum temperature is greater than on the maximum, in some months the mean 0100 temperature is some 3°C higher because of the reservoir. Note, however, that in absolute terms, the lakeside area is not always warmer than the interior. In the daytime the reservoir has a cooling effect until July, with a maximum in April and May (snow melts). The increase in daytime temperatures in the autumn near the reservoir is very slight. At night, the reservoir warms the air by May and this night-warming continues until late autumn. Thus "the reservoir raises night and lowers daytime temperatures from May to July and warms the surrounding air around the clock from September to November". (Note, December-March not discussed, presumably because of freezing.)

Daily range of extreme temperatures is reduced. The shore zone is less likely to frost (eg October, average frequency at shore station, 5; at inland stations, 11). Frost-free season extended by 5 to 40 days (on average, 5 to 15). Reservoir has had no noticeable effect on dates at which mean daily temperatures pass through 5° and 10° levels; only in autumn have the dates been delayed by 2-7 days.

No clear relationships have been seen between the effect of the reservoir and the type of year (ie warm, cold).

The reservoir leads to an increase in absolute humidity near the shore, greatest in summer. In June, July and August it is of the order of 1-2 mb, according to month and time of day, in May and October it is mainly below 0.5 mb. The greatest increase is 2 mb on July nights.

In the shore zone, RH at night has decreased because of the warming effect of the reservoir; in day, it has increased. Mean daily RH is higher in shore zone (due to reservoir) from May to July and lower from August to October.

Fig.4 and Table 2 suggest that the maximum effect of the reservoir at any of the shore stations has been to change temperatures by 2-3°C and absolute humidity by 1.5-2 mb.

As an estimate of the significance of differences of temperature and RH due to the reservoir, these were compared with the mean deviation of the elements at the continental stations. These showed that near the water, temperature changes were most significant at 1 am throughout the warm season, for 1 pm temperatures in May (cooling effect); for mean maximum temperatures in May, for mean minimum temperatures May-September. Changes in absolute humidity were significant in June, July and August.

Cloudiness. Cloud dissipates over reservoir in day but may tend to be more persistent over reservoir at night (instability). On balance, cloud seems to be somewhat reduced by the reservoir; also the reservoir receives less precipitation (c.10 mm less) than the eastern and western shores. On eastern shore, there has been a substantial increase (to 89 mm) in July which, it is concluded, has been induced by the reservoir.

Stations used in this paper for the shore-zone characteristics are within 1 km of the shore line. The spread of reservoir influence away from the shore has not been analyzed but Timofeyev (1963) states that the effect of Rybinsk reservoir in treeless territory can be felt over a distance of 15-20 km at night and 4-6 km in the daytime. Later studies for Kuybyshev and Volgograd reservoirs cite the following distances without day/night differentiation: 5-8 km, 10 km. Vendrov and Malik (1964) indicate an influence of 10 km in open country around the Rybinsk reservoir and substantially more in the isthmus between lakes Ladoga and Onega.

6. Vendrov S L and Malik L K. 1964. An attempt to determine the influence of large reservoirs on local climate. Moscow, Akad Nauk. Izv. Ser. Geog. No.4, pp.35-46

Paper deals with the prediction (by geographic analogues) of the influence of the Pechora-Vychegda-Kama watershed reservoir on temperature and humidity of surrounding territory.

Rybinsk reservoir is used as an analogue. The basis of the determination of the effects of Rybinsk is by studying data from pairs of stations before and after the reservoir was in existence. The object was to determine any change in the differences of temperature and humidity between the stations of a "pair". This change could be attributed to the effect of the reservoir, eg comparison of Rybinsk (c.10 km from reservoir) with Yaroslavl' (90 km) for mean air temperature in September.

	Rybinsk	Yaroslavl'	$\Delta T[R - Y]$
1945-55	11.0	10.1	+ 0.9
1930-40	10.5	10.5	0.0

ΔT = + 0.9

(Reservoir effect)

A comparison of differences between pairs of stations before the reservoir existed enabled random variations to be estimated and led to the conclusion that the smallest quantitative criterion for influence is about 0.3°C.

The final result of the analysis is that 2 zones of influence could be differentiated: (i) a 10-km wide zone which could be called the zone of permanent active influence where the influence of the reservoir is evident each year with a mean value in the various months ranging from 0.5 to 1.5°; (ii) an outer zone of episodic influence where influence is seen only in certain years and the mean value of the reservoir effect may fall to 0.3°C in some months. The boundary of this zone runs 30-50 km from the shore in the direction of the prevailing winds, and substantially nearer the reservoir in other directions.

The overall effect of the reservoir's effect on local climate is as follows (note, only May-October considered):

1) Cooling effect at beginning of warm season, warming effect later. Change over takes place in 2-3 decades in July (based on mean daily temperatures).

   For much of warm season, reservoir cools its surroundings in the day, but warms them very slightly in September and October. Most of warming effect is by night.

2) The reservoir reduced the diurnal temperature range within whole of zone of active influence. Effect most marked in summer, less significant in autumn.

   Above 10 km, effect noticeable only in extreme years, especially those with unusually warm summers.

3) Effect on RH limited to 10 km, probably less on northern shore.

4) Quantitative indicators as follows:

Warming effect on mean monthly daily temperature

0.3-1.0°, on mean monthly night temperatures

0.3-1.3 , on mean monthly daytime temperatures, 0.1-0.9

Cooling effect 0.3-0.6, 0.3-1.0, 0.3-1.9
(order as for warming)

Diurnal temperature ranges reduced by as much as 2.9°. Monthly maxima have been reduced by as much as 3.5°C and monthly minima raised by as much as 4.6°C.

RH differences, raised by as much as 18%.

7. Lyons W A and Wilson J W, 1968. The control of summer-time cumuli and thunderstorms by Lake Michigan during non-lake breeze conditions. Chicago Univ., Dept. Geophys. Sci., Sat. Mesomet. Res. Proj., SMRP Research Paper No.74

Based on a one-day field study over Lake Michigan and the following notes refer only to points which may be of interest in relation to the possible effect on climate of the construction of reservoirs.

p.1 Large cumulus clouds dissipated after about 10 miles of over-water fetch, with no cumulus reforming further out over the lake. There is a layer of about 60 m depth where the overland superadiabatic layer is replaced by an intense inversion through conduction of heat to the water surface. This will not necessarily affect thunderstorms in squall lines and other systems which may often have their origin at much higher levels and remain largely uninfluenced by a large lake.

p.2 Lake breeze will develop over a large area comparable in strength to a sea breeze.

p.4 Changon (1964) concludes that Lake Michigan receives 14% less rain in summer than the surrounding land.

8. Boruško I S, 1965. The influence of lakes and reservoirs on the temperature and humidity of the air over the shores. Leningrad, Glav. Geof. Obs., T. Vyp 182, pp.38-49

/Translation by C Long/

Climate is affected by lakes and reservoirs, because the properties of water differ from those of the surface of the land, whatever the size and latitude of the water bodies.

Radiation balance of water surface greater than that of land surface, partly because of differences in albedo.

Cloudiness less over lakes and reservoirs, especially convection clouds.

Values are quoted for radiation balance for various parts of Russia - the factor by which the balance over water in summer exceeds that of the coast varies between 1.3 and 1.5.

Specific heat of water is 2-5 times as great as that of soil [moderately wet soils have specific heats of: humus 0.22, clay 0.39, sand 0.52].

Extreme temperatures occur later over water, and diurnal and annual ranges are less. Ranges also decreased by turbulent exchange within the water, which may be effective to great depth. Thus more heat can be accumulated within lakes or reservoirs than on land. It must be remembered that the level and volume of reservoirs may be considerably more variable than for lakes.

Data used - standard met observations for 1958-62 from stations near reservoirs (Rybinsk, Kujbyšev and Cimljansk) and natural lakes (Ladoga, Il'men' and Aral. Data for 5 years prior to filling was also used.

When reservoirs are ice-covered in winter, no effect on local climate is detectable. In periods of open water (spring-autumn) there is a rapid transition in temperatures along a narrow belt of coast. The greatest contrasts are in the daytime in spring and summer and the night in autumn. Air temperature decreases linearly with the logarithm of the distance from the water, ie there is only a narrow transition zone (see fig.1, where mean monthly 1300 temperatures are plotted against log distance from water). For smaller (eg Lake Il'men' 2,200 km^2) or elongated (Kujbyšev and Cimljansk reservoirs) water bodies there is no such definite relationship, probably because the air does not spend long enough over the water for the properties to be modified.

A comparison of the tangents of the lines in Fig.1 shows that the effect of water bodies on coastal temperatures increases southward.

The cooling effect of a lake or reservoir is greatest in May in the European USSR, but in April in Central Asia, ie when water temperature is still low because of additional heat lost by melting of ice.

A similar effect is shown for absolute humidity, but the scatter of observations is greater and there is very little change in humidity with distance in areas (such as Lake Ladoga) where the soil is moist. Where there is an effect, it is greatest in June and July when there is maximum evaporation from the water surface.

Graphs of T (or abs. hum.) v. log distance can be used to estimate 1300 values of these elements near reservoirs and lakes.

The effect of reservoirs on local climate has been estimated by comparing "before and after" measurements near the shore with readings outside the zone of influence of the reservoir. The differences (eg ΔT) are calculated for the periods before and after the filling of the reservoir. Reservoir effects can be seen from changes in $\Delta T_1 - \Delta T_2$ (ΔT_1 relate to pre-reservoir period, ΔT_2 to post-reservoir). Method applied to Kujbyšev reservoir for monthly means of temperature and absolute humidities. Stations not more than 80 km apart, to eliminate specific circulation features.

Table 6 shows that the effects of the reservoir were greatest on the coastal station Laiševo. During day, temperature was reduced especially in spring (April, May by more than 2°. At night (0100) it tended to become warmer, by around 1° in summer and autumn. For the average temperature (4 obs per day) the cooling effect was appreciable (1.0-0.5°) only in 2 months (April, May) and was seen up to 2-3 km from the water where the mean width of the reservoir was 10-12 km. In autumn, the same area had a rise of about 0.5°.

On the whole, cooling effect at coastal stations is greater than the warming effect.

The changes in humidity are erratic - overall changes (4 obs/day) are slight and increases and decreases are equally likely.

9. Gregory S and Smith K, 1967. Local temperature and humidity contrasts around small lakes and reservoirs. Weather, XXII (12), 497-505

Introduction summarizes work already done (all abroad).

Lake Balaton (source not clear, possibly Mäde, 1956). 5 stations established along a line normal to the shore at distances up to 700 m inland. 5 obs/day between 0600 and 1800 h of temperature, humidity, wind-speed and cloud amount. Lake caused a diminution of daily temperature maxima by up to 3°C and an increase of humidity (no further details), most of which occurred within 700 m of the shore. Mäde (1956) in his study of the Süsser See showed effects of 1-2°C, within 10-20 m of the lake edge.

Thornthwaite (1958) notes that in terms of monthly averages of air temperature, the Ribinsky (Rybinsk) dam in Russia and Salton Sea and Lake Mead in US make almost no perceptible change in local climate.

Garrett (1956) states, without analysis ..... "minima in the reservoir-filled upper Derwent valley (Derbyshire) may sometimes be 2-4°F higher than those at similar altitude in adjacent valleys that are not submerged and are in other respects more or less similar".

Selset Reservoir Study. 1000 ft OD

Broad deep valley, approx E-W. Water up to 1½ mls x ½ ml, 275 acres.

Screen set up, 2 on northern and 1 on southern shore, with 3 on or near dam road to the east. Wet and dry bulb temperatures, thermographs and grass min. temperatures were recorded. Also a Dines anemograph was set up on south bank. Observations over period 7 August-8 October 1965.

It was not possible to obtain satisfactory results with E-W wind distribution and attention was restricted to occasions of northerly or southerly components (these were hourly and nearly two-thirds, 522, were from the N).

Results for temperature show:

1) T difference between leeward and windward stations < 1°F on 43% occasions. Difference never >5°F.

   Water surface exerted a cooling more often than a warming effect.

2) Analysis of time of day at which heating (cooling) occurs (> 0.5°F) shows a warming effect to leeward from 0100-1000 h, with a leeward cooling from 1200-1800 h. If the temperature differences for each hour are accumulated, 0500 is seen to be the time of greatest warming, 1500 the time of greatest cooling.

3) On a given occasion (1300 on 31/8 to 0900 on 2/9) there were consistent northerlies and analysis of these records shows a diurnal range of temperature on leeward (S) station as 6°F (46-52) as opposed to 10.5 (42-52.5). Warming effect more pronounced and more prolonged than cooling.

4) Absolute humidity. Vapour pressures show that for much of the time air took up moisture as it passed over reservoir (1900 31/8 to 1000 01/9 and 2200 01/9 to 0900 02/9).

5) Relative humidity charts for same period show mainly lower values on southern shore due to the higher temperatures.

Conclusions

Climatic modifications due to reservoirs are smaller and more variable than is sometimes supposed. For much of the time advective influences amount to less than 1°F and although a diurnal cycle is detectable, the maximum effect will rarely exceed 5°F.